Report of the A.S.T.M. Task Group Studying the Wyzenbeek Precision Wear Test Meter

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SYNOPSIS

A study of the Wyzenbeek Precision Wear Test Meter was made to determine its suitability for use as a standard instrument for determining the abrasion resistance of textiles. The results of two interlaboratory tests, which included consideration of end points and abradants, indicate that the severity of abrasion among the units is too variable to permit the use of the Wyzenbeek apparatus for establishing interlaboratory standards. Individual instruments were found to be sufficiently precise for evaluating differences among fabrics. A number of suggestions for improving the technique of operation are included.

A PRINCIPAL objective of the Task Committee on Abrasion Testing (under Subcommittee B-1 on Methods and Machines, Section 1 on Methods of Testing, of A.S.T.M. Committee D-13 on Textile Materials) is the examination of various commercial abrading instruments to determine their suitability for use in establishing standard methods. Task groups have been formed within the committee to study the Taber Abrader, the U. S. Testing Co.'s abrader and the Wyzenbeek Precision Wear Test Meter, as a canvas had indicated that these instruments are in widest use (1).[3] The present paper discusses the work of the task group investigating the Wyzenbeek apparatus (Fig. 1). This machine is manufactured by Wyzenbeek and Staff, Inc., Chicago, Ill.

Methods of evaluating the extent of damage fall into two classes, namely, those utilizing visual evidence of degradation, generally employed when appearance is a factor (woolen outerwear, plush, etc.), and those considering the change in some mechanical characteristic, usually breaking strength, after a given period of abrasion. The latter method is used primarily for utility fabrics (work garments, webbings, etc.). Abradants are of many types, including metal screening, abrasive cloths and papers, standard fabrics, and the test cloth itself. Statistical control is used by some technicians. Some operators employ the vacuum device furnished by the manufacturer to remove the detritus, others use a brush for this purpose, and the rest do neither. A choice of operating conditions in so far as load, tension, and cycles of abrasion are concerned is possible by virtue of the construction of the instrument.

Because of the many possible variations in technique, it was decided first to ascertain satisfactory conditions of load and tension for performing the test on a readily available cloth and using a single machine. After standard abrading conditions for this unit were selected, a test was initiated to determine the consistency of results among a number of instruments. Two types of fabrics were used as test cloths to determine the adequacy of subjective methods for estimating end points. The results of this interlaboratory study exhibited a high degree of variation. As this might have been caused by a lack of precision in the subjectively determined end-points, it was deemed advisable to conduct a second interlaboratory Wyzenbeek test, using an objective end point by ascertaining the discriminatory faculty of the instrument with regard to ranking a number of test fabrics.

PRELIMINARY STUDIES

Tension, Load, and Cycles:

The Wyzenbeek instrument permits the test specimen to be subjected to tensions ranging from 1 to 6 lb. and to compressional loads of from 1 to 5 lb.

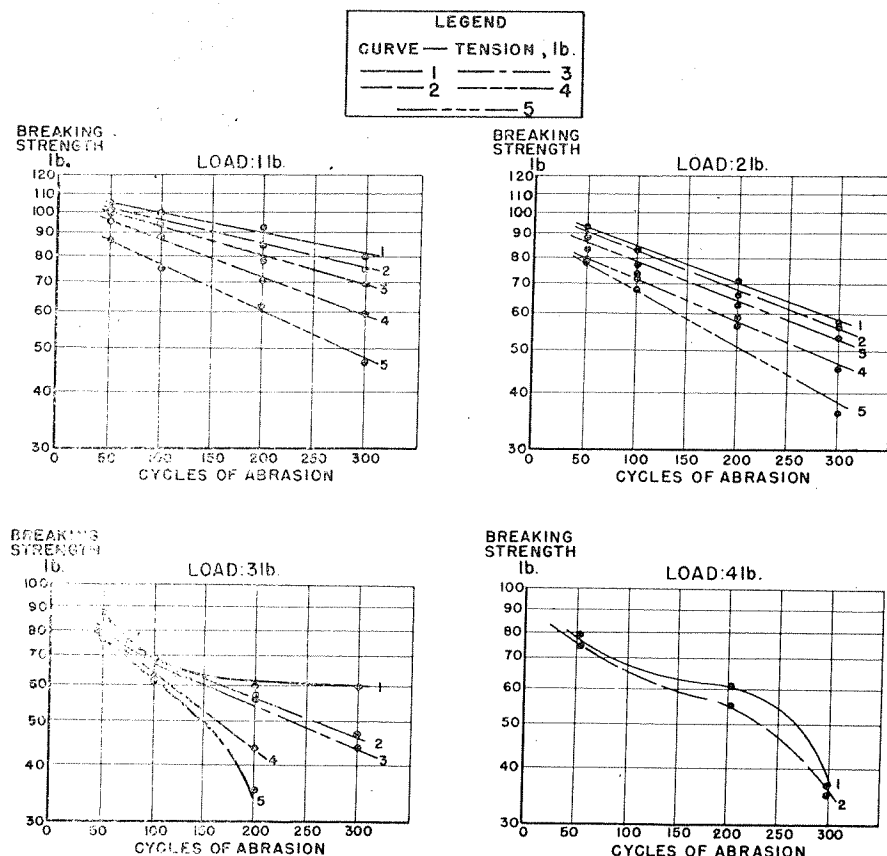Fig. 1.—Wyzenbeek Precision Wear Test Meter.

Fig. 2.—Effect of Tension on Breaking Strength at Various Loads. Wyzenbeek Precision Wear Test Meter.

NOTE:—Breaking Strength of Unabraded Herringbone Twill: 121.3 lb.

conformance of the operator and of the tensile tester. The specimens were abraded under several tensions and loads for various cycle stages.

The results, presented graphically in Fig. 2, indicate that, within limits, semilogarithmic relationships exist between the amount of abrasion and the loss in breaking strength. A satisfactory end point may be obtained by choosing any combination of values for the parameters of load, tension, and cycles of abrasion which lie within these limits.

End Points and Abradants:

Once satisfactory operating conditions for a given fabric were ascertained by use of an objective end point, the next step was to investigate a method employing visual end points. This latter method (5) consists of abrading a $2\frac{7}{8}$ by 9-in. specimen folded in "S" fashion to $1\frac{7}{8}$ by 9 in. to simulate edge abrasion and $1\frac{7}{8}$ by 9-in. flat strips to simulate plane wear. The number of cycles required to reach the following end points is noted:

    A—*First Wear.*—Any radical disturbance of surface, as fuzzing, scuffing, or pilling.

    B—*First Rupture of Yarn.*—Any rupture visible with a pick glass.

    C—*Threadbare.*—The detachment of yarn or yarns parallel to the long direction of the specimen as a

over 4 sq. in. of abraded area by means of two independent series of adjustable cantilever clamps. The specimen is forced by a rubber pad against an oscillating curved abrasive surface for the desired number of cycles. Three or four specimens may be tested simultaneously, depending upon the Wyzenbeek model used.

The apparatus used for determining satisfactory values of the parameters of tension, load, and length of abrasion for a particular fabric was a four-arm machine whose drum oscillated at the rate of 90 cycles per minute. The vacuum device had been removed for ease of operation. No. 320 Aloxite cloth* was employed as the abradant and was changed after each run. Before testing, care was taken that each specimen was free of loose threads, but no attempt to remove detritus was made during the course of the runs. The fabric selected was an 8.5-oz. vat-dyed herringbone twill. The loss in warp tensile strength after warpwise abrasion was chosen as the measure of abrasion resistance. Control-chart technique was employed to determine homogeneity of results from the four test arms and statistical

TABLE I.—NUMBER OF CYCLES TO REACH FIRST RUPTURE AND THREADBARE END POINTS. PRELIMINARY PHASE.

(LOAD: $2\frac{1}{2}$ LB. TENSION: 2 LB.)

End Point[a]	Warp		Filling		Warp Folded		Filling Folded	
	Cycles	Per cent[b]	Cycles	Per cent[b]	Cycles	Per cent[b]	Cycles	Per cent[b]
10.5-Oz. WOOL SERGE Fabric as Abradant								
A	9 890	7	8 750	7	7 600	7	5 570	7
B	113 100	84	110 550	83	89 800	86	62 390	84
C	135 400	100	120 700	100	103 650	100	74 600	100
No. 320 Aloxite as Abradant								
A	75	50	50	38	30	43	25	42
B	130	87	110	84	60	85	50	85
C	150	100	130	100	70	100	60	100
No. 400 Aloxite as Abradant								
A	80	36	65	34	40	42	30	40
B	180	82	150	79	75	79	60	80
C	220	100	190	100	95	100	75	100
No. 500 Silica as Abradant								
A	120	41	90	43	55	46	50	45
B	250	86	170	81	100	83	90	82
C	290	100	210	100	120	100	110	100
22-oz. WOOL SERGE Fabric as Abradant								
A	16 080	6	15 040	6	14 400	6	12 890	6
B	234 160	93	232 700	95	232 080	98	201 150	90
C	251 250	100	246 100	100	236 200	100	222 650	100
No. 320 Aloxite as Abradant								
A	270	53	210	55	110	58	60	40
B	390	76	300	79	150	79	100	67
C	510	100	380	100	190	100	150	100

[a] A = First wear. B = First rupture. C = Threadbare.
[b] Percentage $= 100 \times \dfrac{\text{Cycles to reach given end point}}{\text{Cycles to reach end point } C}$

result of multiple rupture of crosswise yarns.

For this phase, a 10.5-oz. wool serge was abraded both flat and folded in the warp and filling directions using the following abradants: the fabric itself, No. 320 Aloxite, No. 400 Aloxite, and No. 500 silica cloths. A sample of 22-oz. serge was tested similarly, except that the last two abradants were omitted. The number of cycles required to reach each end point and the ratios of cycles for end points A and B to cycles for end point C, expressed as percentages, are presented in Table I.

The results of this part may be summarized as follows:

1. As observation of surface disturbance is entirely subjective, wide variation in results using end point A may be expected.

2. The ratio of the cycles for end point B to the cycles for end point C appears to be fairly constant, regardless of specimen or abradant.

3. For heavier textiles, the use of the test fabric as the abradant necessitates an excessively long period of abrasion to reach a satisfactory end point.

First Interlaboratory Test

Before a decision could be reached as to the applicability of the Wyzenbeek Precision Wear Test Meter to a standard procedure, it was necessary to ascertain whether instruments in different laboratories were potentially capable of yielding reproducible and consistent results. It must be noted that although several articles have been written about this apparatus (2, 4, 5), no broad attack on the problem of interlaboratory correlation has been reported. A test was therefore formulated to determine the internal consistency of various instruments and the reproducibility of interlaboratory results. The cooperating agencies were furnished samples of 8.5-oz. cotton herringbone twill and 10.5-oz. wool serge, two commonly used abradants (No. 320 Aloxite cloth and No. 0 emery metallographic paper) and a test plan. The plan detailed the conditions of load and tension, indicated how to prepare the specimens and how often to observe the progress of the abrasion, and defined the visual end points. The end points chosen were: A, first wear; B, first rupture; and C, threadbare; as described previously.

Adequate returns were received from ten laboratories. The data for the first wear end point were so scattered as to show that this end point is meaningless for purposes of interlaboratory comparison. The values for the other end points, which are shown in Table II,

were of sufficient consistency to permit analysis. As the data for the cotton and the wool fabrics exhibit similar tendencies, only those of the latter fabric are shown. Cursory examination of the data indicates that the number of cycles of abrasion required to reach a described visual end point varies widely, indicating slight agreement among laboratories. However, a closer study shows that some agencies rank consistently high whereas others rank consistently low for end points B and C. The data for end points B and C were arrayed to allow determination of the rank correlation coefficients (Spearman's ρ) for the ten laboratories with the following test variables:

(a) Directions of abrasion.
(b) Abradants.
(c) End points.

TABLE II.—CYCLES TO REACH END POINTS FOR 10.5-OZ. WOOL SERGE.
FIRST RUPTURE END POINT B

| No. 0 Emery Paper | | | | | | | | No. 320 Aloxite Cloth | | | | | | | |
| Warp | | Filling | | Warp Folded | | Filling Folded[a] | | Warp | | Filling | | Warp Folded | | Filling Folded | |
Lab.	n	Lab.	n	Lab.	n	Lab.	n	Lab.	n	Lab.	n	Lab.	n	Lab.	n
H	830	H	1210	H	256	I	263	I	225	G	228	F	87	C	100
I	638	I	638	C	240	C	260	F	224	I	220	C	80	F	75
E	580	E	620	I	238	H	256	H	210	F	218	H	62	H	64
C	540	G	558	F	203	F	200	C	180	H	178	I	50	G	52
D	540	D	500	G	170	G	168	D	165	C	160	L	50	I	52
G	478	C	480	L	170	K	158	G	158	D	120	G	46	L	50
L	450	L	390	K	142	D	140	L	120	L	120	D	45	D	45
F	428	F	355	D	140	E	110	E	80	J	110	E	30	K	32
J	221	J	355	E	100	J	99	K	74	E	100	J	28	E	30
K	218	K	218	J	84			J	59	K	82	K	28	J	28

THREADBARE END POINT C

| No. 0 Emery Paper | | | | | | | | No. 320 Aloxite Cloth | | | | | | | |
| Warp | | Filling | | Warp Folded | | Filling Folded | | Warp | | Filling | | Warp Folded | | Filling Folded | |
Lab.	n	Lab.	n	Lab.	n	Lab.	n	Lab.	n	Lab.	n	Lab.	n	Lab.	n
I	1200	H	1844	I	538	C	720	F	314	I	305	F	124	C	140
H	1184	I	1200	C	520	I	388	H	298	C	280	C	120	F	105
C	1080	C	1100	H	306	H	280	C	280	F	276	I	95	I	102
D	900	L	800	L	280	F	278	I	250	G	270	G	92	G	90
L	890	D	780	F	279	G	272	D	235	H	250	H	90		
E	700	E	700	G	266	L	260	G	196	D	195	L	70	L	70
G	604	G	696	D	220	D	240	L	150	L	170	D	60	D	60
F	596	F	506	K	166	K	186	E	140	J	168	J	56	J	54
J	413	J	474	J	136	E	170	J	102	E	140	E	50	E	50
K	218	K	218			J	136	K	76	K	82	K	36	K	36

a Laboratory L value not received in this case.

TABLE III.—RANK CORRELATION COEFFICIENTS[a] FOR TEN INSTRUMENTS. FIRST INTERLABORATORY TEST.

BETWEEN DIRECTIONS OF ABRASION[b]

| Abradant | First Rupture End Point versus Threadbare End Point | | | | | | | |
| | W versus F | | WF versus FF | | W versus F | | WF versus FF | |
	Serge	HBT	Serge	HBT	Serge	HBT	Serge	HBT
Emery	0.96	0.79	0.95	0.82	0.98	0.93	0.94	0.60
Aloxite	0.77	0.25	0.94	0.92	0.82	0.67	0.95	0.74

BETWEEN ABRADANTS

| Fabric | No. 0 Emery versus No. 320 Aloxite | | | | | | | |
| | First Rupture End Point | | | | Threadbare End Point | | | |
	W	F	WF	FF	W	F	WF	FF
Serge	0.58	0.47	0.85	0.88	0.59	0.56	0.77	0.94
Herringbone twill	0.49	0.28	0.90	0.92	0.38	0.55	0.52	0.88

BETWEEN END POINTS

| Fabric | First Rupture versus Threadbare | | | | | | | |
| | Warp | | Filling | | Warp Folded | | Filling Folded | |
	Emery	Alox.	Emery	Alox.	Emery	Alox.	Emery	Alox.
Serge	0.89	0.92	0.78	0.88	0.89	0.90	0.98	0.90
Herringbone twill	0.93	0.47	0.92	0.76	0.55	0.72	0.83	0.85

a Spearman's rank correlation coefficient, ρ, is expressed by the following formula:

$$\rho = 1 - \frac{6\Sigma d^2}{N(N^2 - 1)}$$

where d = difference in rank between paired items in two series, and N = number of ranks.
b W, F, WF, FF designate warp, filling, warp folded, and filling folded, respectively.

Ranks were assigned to the number of cycles from the highest to the lowest. A value of one for ρ would indicate perfect association and zero none. The relatively high values of most of the coefficients, as seen in Table III, suggest that although the laboratories might differ among themselves, each, individually, is quite consistent.

To further substantiate the rankings of the laboratories, a check was made for any possible fortuitousness of the results by performing eight one-way analyses of variance of rank for each of the four directions of abrasion (warp, filling, warp folded, and filling folded) for the first rupture and threadbare end points for each of the two abradants. The design of the analyses is illustrated by the following outlines:

	WARP[a] Laboratory											FIRST RUPTURE—EMERY[b] Laboratory										
Group	1	2	3	4	5	6	7	8	9	10		Group	1	2	3	4	5	6	7	8	9	10
FR-E...												W....										
FR-A...												F....										
T-E....												WF....										
T-A....												FF...										

[a] Repeated for Filling, Warp Folded, and Filling Folded.
[b] Repeated for First Rupture—Aloxite, Threadbare—Emery, and Threadbare—Aloxite.

Thus for each of the eight sets there are four rows and ten columns. Following the method suggested by Friedman (3), the statistical test is set up to determine whether the different columns, which show the rankings of each laboratory, came from the same population and therefore would indicate that the ranks would be due to chance and consequently that the laboratories are inconsistent.

The statistic χ_r^2 was computed[4] which

[4] The χ^2 distribution $= Ns^2/\sigma^2$, where:

	General Case	For Ranked Data
Degrees of freedom for means..	$\frac{N}{\frac{1}{2}(p + 1)}$	$\frac{1}{2}(p + 1)$
Mean		
Sample variance...	s^2	$\sum_{j=1}^{10} \frac{1}{p}[r_j - \frac{1}{2}(p + 1)]^2$
Population variance of means..	$\frac{\sigma^2}{N}$	$\frac{p^2 - 1}{12n}$

Thus, for ranked data

$$\chi_r^2 = \frac{12n}{p(p + 1)} \sum_{j=1}^{10} [\bar{r}_j - \frac{1}{2}(p + 1)]^2$$

where:
$\bar{r}_j$ = average of jth column,
n = number of rows = 4, and
p = number of columns or ranks = 10.
For small values of n and large values of p, the significance of χ_r^2 is tested by considering

$$\frac{\chi_r^2 - (p - 1)}{\left[\frac{2(n - 1)(p - 1)}{n}\right]^{\frac{1}{2}}}$$

as a normally distributed variant with zero mean and unit variance.
has the χ^2 (chi-square) distribution when the ranking is random. The results of these analyses indicate that the probability that the rankings were due

to chance alone in each of the eight sets for both the serge and the herringbone twill was less than one in a thousand, and illustrate the marked consistency of the ten laboratories in evaluating the abrasion resistance under eight different conditions.

Having determined that the laboratories were consistent as to their relative standings in the number of cycles necessary to reach a given visual end point, exclusive of the first wear end point, under various experimental conditions, the analysis then considered the internal consistency within each laboratory. The assumption was made that there should be a similarity of ratios of the number of cycles to abrade each fabric fillingwise, warpwise folded, and filling-wise folded, respectively, to the warp which was considered to be 100. This similarity should occur for the first rupture and the threadbare end points for each type of abradant. A χ^2 (chi-square) test was performed involving four rows (warp, filling, warp folded, filling folded), two columns (first rupture and threadbare end points), and three degrees of freedom. A laboratory was deemed to be inconsistent when the chi-square computed could have occurred by chance less than one time in a hundred. The results of this analysis are shown in Table IV.

Parenthetically it may be stated that several laboratories which exhibited poor internal consistency later indicated that operators had been changed during the test or that the decision as to the proper visual end point had been modified.

In a separate attempt to illustrate consistency, the percentages of cycles to reach the first rupture end point to the cycles to reach the threadbare end point

were calculated. When these data are plotted as in Fig. 3 the evidence of internal consistency of the laboratories is perhaps more easily observed. For example, all 16 percentages for laboratory F lie between 70 and 79. Similarly, 13 of the 16 percentages for laboratory D lie between 60 and 76. For company J, on the other hand, the values vary from 10 to 81 per cent. A vivid illustration of the differences in visual end points as judged by the various agencies is furnished in Fig. 4.

Conclusions from the First Interlaboratory Test:

Using the Wyzenbeek Precision Wear Test Meter as an interlaboratory test instrument for abrading 8.5-oz. cotton herringbone twill and 10.5-oz. wool serge shows that:
1. There is a high consistency among the laboratories in so far as ranking is concerned.
2. There is a low consistency among the laboratories in so far as actual numerical values are concerned.
3. There is a high association between the first rupture end point and the threadbare end point, indicating the lack of necessity for abrading to the latter stage.
4. Certain laboratories exhibit decidedly higher internal consistency than others.

SECOND INTERLABORATORY TEST

Replies to a questionnaire circulated after the first test showed that the age of the instruments used varied from a few months to 16 yr. and that many machines had not been calibrated since leaving the manufacturer. Therefore, before the second test was begun the cooperating laboratories were requested

TABLE IV.—CONSISTENCY OF LABORATORIES.

HERRINGBONE TWILL FABRIC

Laboratory........	C	D	E	F	G	H	I	J	K	L
Abradant:										
Emery..........	G	G	G	G	G	G	G	P	P	P
Aloxite..........	G	G	P	G	P	G	G	P	G	P

SERGE FABRIC

Laboratory........	C	D	E	F	G	H	I	J	K	L
Abradant:										
Emery..........	G	G	G	G	G	G	G	G	G	G
Aloxite..........	G	G	G	G	G	G	G	G	G	G

NOTE.—G = Good consistency. P = Poor consistency.

to return their instruments to the maker for overhauling and calibrating. Upon completion of these arrangements the machines presumably were in first-class condition.

The purpose of this second interlaboratory test was to compare the similarity of the machines in regard to the amount of abrasion occurring in a number of fabrics. A second objective was to ascertain the reproducibility and

consistency of the results from each laboratory for the purpose of obtaining an indication of the causes contributing to the variability of the values both within and among the laboratories.

In order to get conclusive results concerning the efficacy of the Wyzenbeek apparatus as an interlaboratory instrument, the test specimens were pre-cut and the breaking strengths of the abraded specimens were determined on a single tensile tester by a single operator, both being in statistical control. By indicating which specimens were to be abraded on a given arm, the experiment permitted the assignment of a large portion of the total variation to specific causes. Each cooperating member received randomized specimens of five fabrics, two abradants, and a test directive, which read as follows:

ABRASION TEST METHOD

Scope:

To determine the reproducibility of the characteristics of the Wyzenbeek Precision Wear Test Meter among laboratories in terms of a selected end point of abrasion. For this study, the end point is the per cent loss in breaking strength. The abraded specimens will be evaluated at the Philadelphia Quartermaster Depot with a single Scott Vertical Tensile Tester. Statistical control techniques will be utilized.

Specification:

Machine:
Wyzenbeek Precision Wear Test Meter.
Number of arms: 3 or 4.
Rate of oscillation: approximately 90 cycles (double rubs) per minute.
Atmospheric Conditions:
Temperature—70 ± 2 F.
Relative humidity—65 ± 2 per cent.

Design of Experiment:

Number of Specimens Abraded								
	Aloxite				Emery			
Fabric (Cottons)	Arm:	1	2	3	4	Arm:	1 2 3 4
Herringbone twill........		7	7	7	7		7 7 7 7
Poplin........		7	7	7	7		7 7 7 7
Sateen*a*........		7	7	7	7		7 7 7 7
Sateen (filling)*a, b*.....		7	7	7	7		7 7 7 7
2/1 Twill.....		7	7	7	7		7 7 7 7

a Filling flush.
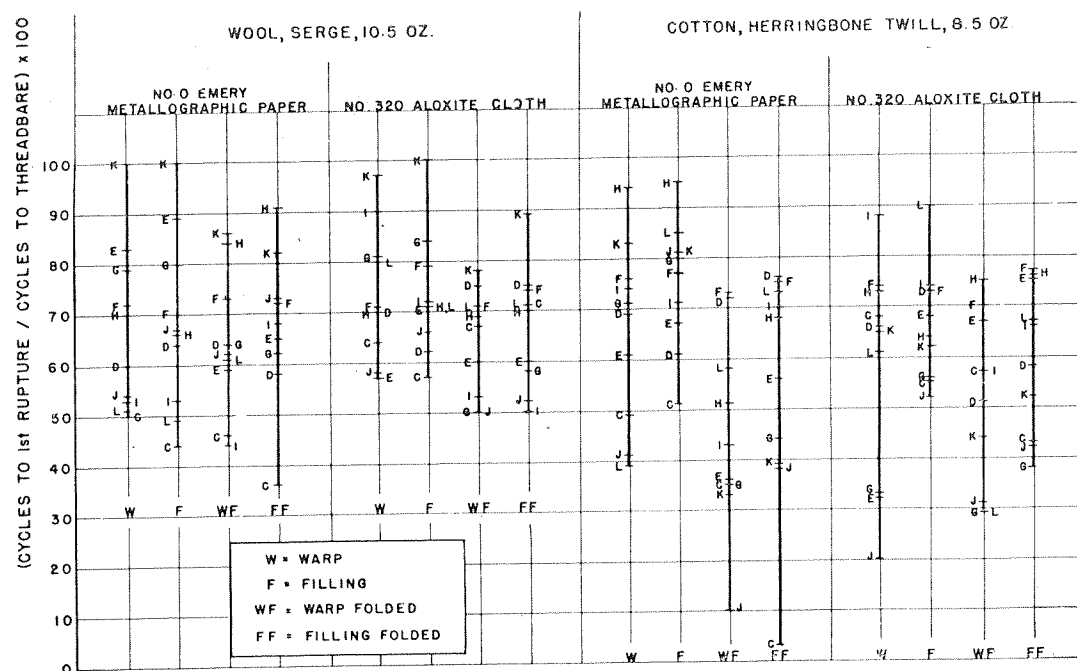*b* The specimens of all fabrics except this one were cut warpwise.

Fig. 3.—Percentages of Cycles to Reach First Rupture End Point to Cycles to Reach Threadbare End Point.
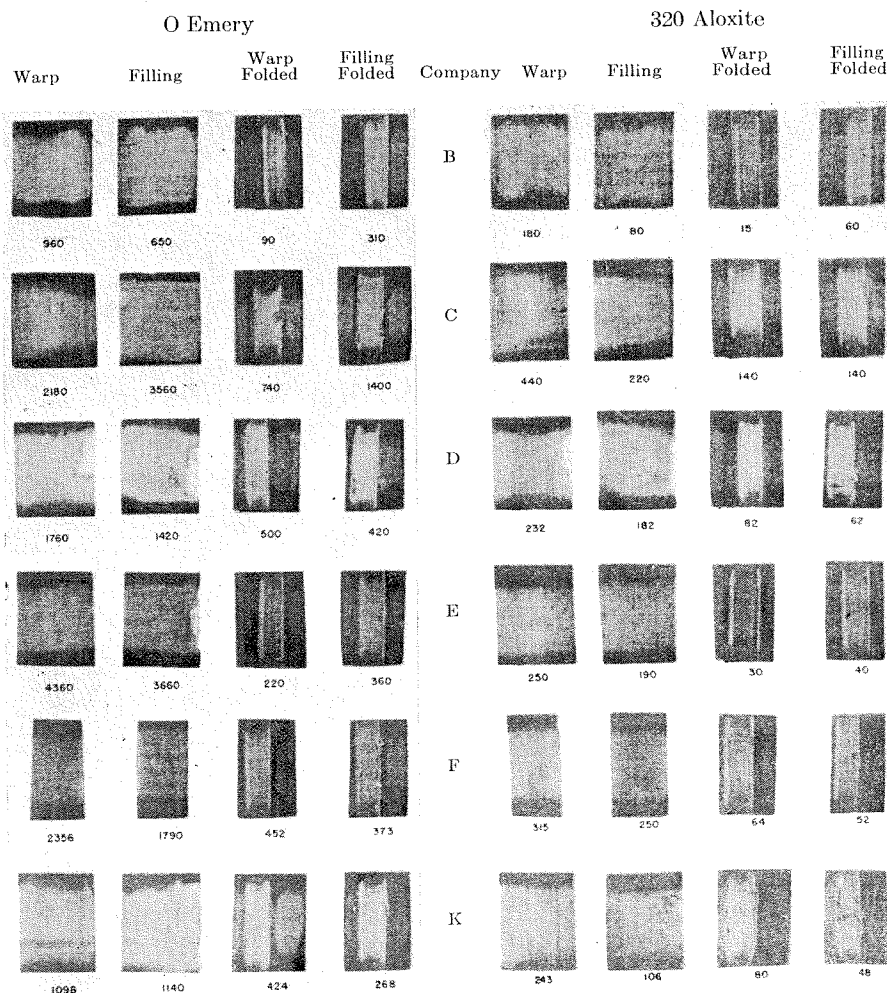

Fig. 4.—Cotton, Herringbone Twill, 8.5 oz.
Numbers denote cycles to threadbare stage.

TABLE V.—AMOUNT OF ABRASION OF 14 INSTRUMENTS ON FOUR FABRICS.

EMERY ABRADANT

Laborator	Herringbone Twill RBS[a] $\overline{X}$, lb.	Dev. from $\overline{\overline{X}}$, %	B. S.[b] Loss Per cent	Rank	Poplin RBS[a] $\overline{X}$, lb.	Dev. from $\overline{X}$, %	B. S.[b] Loss Per cent	Rank	Sateen RBS[a] $\overline{X}$, lb.	Dev. from $\overline{X}$, %	B. S.[b] Loss Per cent	Rank	2/1 Twill RBS[a] $\overline{X}$, lb.	Dev. from $\overline{X}$, %	B. S.[b] Loss Per cent	Rank
No. 1	93	0.3	19	1	96	1.7	29	2	67	1.1	43	3.5	65	5.9	43	3.5
No. 2	82	12.1	28	1	85	10.0	37	2	58	12.5	51	4	59	14.6	48	3
No. 3	94	0.8	18	1	102	8.0	24	2	65	2.0	45	4	72	4.2	36	3
No. 4	97	4.0	15	1	109	15.5	19	2	75	13.1	37	3	70	1.3	38	4
No. 5	93	0.3	19	1	85	10.0	37	2	58	12.5	51	4	69	0.1	39	3
No. 6	99	6.1	13	1	89	5.7	34	2	64	3.5	46	4	69	0.1	39	3
No. 7	94	0.8	18	1	105	11.2	22	2	74	11.6	38	4	74	7.1	35	3
No. 8	83	11.0	27	1	81	14.2	40	2	43	35.1	64	4	66	4.5	42	3
No. 9	99	6.1	13	1	101	7.0	25	2	82	23.7	31	3	74	7.1	35	4
No. 10	87	6.8	24	1	84	11.0	38	2	59	11.0	50	4	61	11.7	46	3
No. 11	104	11.5	9	1	114	20.8	15	2	87	31.2	27	4	84	21.6	26	3
No. 12	94	0.8	18	1	87	7.8	36	2	63	5.0	47	4	65	5.9	43	3
No. 13	90	3.5	21	1	91	3.6	33	2	62	6.5	48	4	68	1.6	40	3
No. 14	97	4.0	15	1	93	1.5	31	2	71	7.1	40	4	72	4.2	36	3
Average	93.3	4.9	18.3		94.4	9.1	30.0		66.3	12.6	44.1		69.1	6.4	39.0	
Minimum	82	0.3	9		81	1.5	15		43	1.1	27		59	0.1	26	
Maximum	104	12.1	28		114	20.8	40		87	35.1	51		84	21.6	48	
Range	22	11.8	19		33	19.3	25		44	34.0	24		25	21.5	22	

ALOXITE ABRADANT

Laborator	RBS lb.	Dev %	Loss Per cent	Rank	RBS lb.	Dev %	Loss Per cent	Rank	RBS lb.	Dev %	Loss Per cent	Rank	RBS lb.	Dev %	Loss Per cent	Rank
No. 1	60	9.5	48	1	56	26.1	59	2	27	19.6	77	4	36	9.1	68	3
No. 2	47	29.1	59	1	32	27.9	76	2	17	49.4	86	4	22	44.4	81	3
No. 3	80	20.7	30	1	59	32.9	56	2	38	13.1	68	4	43	8.6	62	3
No. 4	72	8.6	37	1	49	10.4	64	2	42	25.0	65	3	35	11.6	69	4
No. 5	84	26.7	27	1	43	3.2	68	3	29	13.7	76	4	46	16.2	59	2
No. 6	68	2.6	41	1	51	14.9	62	3	33	1.8	72	4	45	13.6	60	2
No. 7	64	3.5	44	1	47	5.9	65	3	37	10.1	69	4	44	11.1	61	2
No. 8	48	27.6	58	1	34	23.4	75	3	28	16.7	76	4	36	9.1	68	2
No. 9	86	29.7	25	1	60	35.1	56	3	57	69.6	52	2	48	21.2	58	4
No. 10	60	9.5	48	1	37	16.7	73	3	22	34.5	81	4	38	4.0	66	2
No. 11	82	23.7	28	1	72	62.2	47	2	59	75.6	50	3	53	33.8	53	4
No. 12	72	8.6	37	1	32	27.9	76	3.5	29	13.7	76	3.5	39	1.5	66	2
No. 13	51	23.1	55	1	20	55.0	85	4	22	34.5	81	3	37	6.6	67	2
No. 14	54	18.6	53	1	29	34.7	79	4	31	7.7	74	3	32	19.2	72	2
Average	66.3	17.3	42.1		44.4	26.9	67.2		33.6	27.5	71.6		39.6	15.0	65.0	
Minimum	47	2.6	25		20	3.2	47		17	1.8	50		22	1.5	53	
Maximum	86	29.7	59		72	62.2	85		59	75.6	86		53	44.4	81	
Range	39	27.1	34		52	59.0	38		42	73.8	36		31	42.9	28	

[a] Residual breaking strength (average of 28 values).
[b] Breaking strength.

Procedure:

1. For each fabric, abrade seven of the eight sets of four specimens. The extra set has been included in case of error or necessity for recheck.

2. Abrade specimens marked "1" on arm 1, "2" on arm 2, etc. For three-armed models, disregard specimens marked "4."

3. Use a new sheet of abradant for each set of specimens.

4. Specimens are to be inserted into arm clamps so that the side of the fabric marked in red will rest against the abradant.

5. Employ the following test conditions:

(a) 2-lb. load.

(b) 2-lb. tension.

(c) 250 continuous cycles.

6. Identify and keep in chronological order each set of specimens by tagging the strips together and marking Run 1, Run 2, .. , Run 7.

7. Return sets of abraded specimens and unused fabric strips to Philadelphia.

The fabrics were abraded warpwise and broken warpwise except for one of the groups of sateen which was abraded and broken fillingwise. The two groups of sateen, basically the same fabric, were included to determine whether
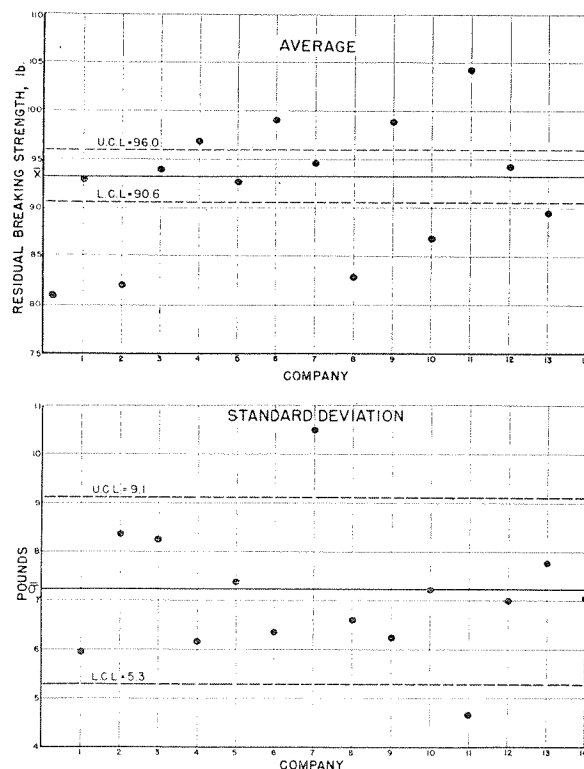

Fig. 5.—Control Charts on the Amount of Abrasion and Variability of Fourteen Wyzenbeek Machines.

warpwise abrasion affects the breaking strength of the protected yarns. It was noted that regardless of direction of abrasion of filling-flush sateen, the filling yarns bore the brunt of the degradation. As the loss in warp breaking strength after 250 cycles was negligible, data for the warpwise-cut sateen were not included in the following analysis.

Comparison of Amount of Abrasion:

Considering one fabric abraded by one medium on a four-arm apparatus (the model used by all but one laboratory), it is seen that this experiment yielded 28 individual values for the residual breaking strength per laboratory. Table V compares the average amount of abrasion of the 14 instruments studied for the four fabrics using emery and Aloxite abradants. The values show a dissimilarity in the performance of the various machines, for the average range of the percentage loss in strength after abrasion is approximately 23 per cent when emery is used and 33 per cent when Aloxite is the abradant. Despite these wide ranges with emery abrasive there are but three different rankings of the four fabrics. Eleven of the 14 laboratories ranked the materials identically, one rated the third and fourth fabrics equally, while the remaining two reversed the third and fourth fabrics. Use of the Aloxite resulted in six different rankings, showing the greater consistency of the emery.

The significance of the differences in the amount of abrasion of each of the four fabrics by the various companies may be illustrated by control charts. The data for the charts are shown in Table VI and a typical example is presented as Fig. 5. Values falling outside the control limits differ significantly from the over-all average, as the probability is less than one in twenty that they do so by chance.

The consistency of the individual Wyzenbeek machines is illustrated by Fig. 5, which indicates the linear relationships among the average residual breaking strength of all four fabrics from each laboratory using emery and Aloxite abradants. The data show, in short, that the differences in the average residual breaking strength values of the 14 laboratories would be caused primarily by differences among the machines rather than by differences within the fabrics or to variations within any given apparatus.

Reproducibility and Consistency of Results:

The variability or dispersion of the breaking strength values of the 28 abraded specimens of each fabric for each laboratory is shown in Table VI

TABLE VI.—VARIABILITY OF ABRASION OF 14 INSTRUMENTS ON FOUR FABRICS.

Laboratory	Standard Deviation, σ, lb.[a]							
	Herringbone Twill		Poplin		Sateen		2/1 Twill	
	Emery	Alox.	Emery	Alox.	Emery	Alox.	Emery	Alox.
No. 1	6.0	10.2	8.1	8.7	11.5	6.1	10.3	7.9
No. 2	8.3	12.9	12.5	9.9	8.2	5.9	7.9	7.9
No. 3	8.3	10.6	8.6	7.4	8.9	6.0	6.7	6.3
No. 4	6.2	9.4	6.5	11.3	8.9	9.6	7.4	5.9
No. 5	7.4	6.5	10.8	9.2	10.0	5.7	10.3	8.0
No. 6	6.3	11.6	10.8	13.3	9.4	11.0	9.7	8.8
No. 7	10.5	11.1	7.8	11.3	10.1	7.8	8.0	7.5
No. 8	6.6	7.2	11.0	8.6	6.7	5.5	9.7	7.5
No. 9	6.2	6.9	13.1	13.5	8.9	13.1	5.8	9.9
No. 10	7.2	14.8	9.1	13.9	8.7	9.8	10.9	12.0
No. 11	4.7	7.3	6.9	8.6	12.2	12.7	8.5	10.0
No. 12	7.0	8.8	14.7	4.8	9.5	7.7	8.1	10.7
No. 13	7.8	11.9	10.4	17.1	9.4	11.6	8.1	12.9
No. 14	7.1	11.9	9.6	13.9	9.5	7.6	8.1	8.4
$\bar{\sigma}$, lb.[b]	7.2	10.4	10.3	11.3	9.5	9.0	8.7	9.1
$\bar{\bar{X}}$, lb.[c]	93.3	66.3	94.4	44.4	66.3	33.6	69.1	39.6
$\bar{X}$ Chart:								
UCL, lb.[d]	96.0	70.2	98.3	48.7	69.9	37.0	72.4	43.0
LCL, lb.[d]	90.6	62.4	90.5	40.1	62.7	30.2	65.8	36.2
σ Chart:								
UCL, lb.[e]	9.1	13.2	13.1	14.3	12.0	11.4	11.0	11.5
LCL, lb.[e]	5.3	7.6	7.5	8.3	7.0	6.6	6.4	6.7

[a] $\sigma = \sqrt{\dfrac{\Sigma(x - \bar{x})^2}{N - 1}}$.

[b] $\bar{\sigma}$ = Square root of average of 14 individual σ^2,s.

[c] Values from Table V.

[d] For $\bar{\bar{X}}$ control chart: Upper control limit, UCL $= \bar{\bar{X}} + 2\bar{\sigma}/\sqrt{28}$. Lower control limit, LCL $= \bar{\bar{X}} - 2\bar{\sigma}/\sqrt{28}$.

[e] For σ control chart: Upper control limit, UCL $= \bar{\sigma} + 2\bar{\sigma}/\sqrt{56}$. Lower control limit, LCL $= \bar{\sigma} - 2\bar{\sigma}/\sqrt{56}$.

TABLE VII.—OVER-ALL COMPARISON OF AMOUNT OF ABRASION AND REPRODUCIBILITY OF 14 WYZENBEEK TESTERS.

Laboratory	Residual Breaking Strength of 112 Specimens, lb.						Reproducibility, σ_E^2/σ_A^2	Consistency, χ^2
	Emery Abradant			Aloxite Abradant				
	$\bar{X}$	σ_E^2	σ_E^*	$\bar{X}$	σ_A^2	σ_A^*		
No. 1	80.1	77.10	8.8	44.7	53.53	7.3	1.44	3.1
No. 2	70.9	66.35	8.2	29.4	62.18	7.9	1.07	5.0
No. 3	83.3	65.52	8.1	54.7	60.39	7.8	1.08	4.0
No. 4	87.6	53.10	7.3	49.4	45.62	6.8	1.16	5.2
No. 5	76.1	91.48	9.6	50.5	41.78	6.5	2.19[a]	7.8[b]
No. 6	80.4	51.60	7.2	49.0	52.73	7.3	0.98	1.4
No. 7	86.7	77.80	8.8	48.0	64.81	8.1	1.10	3.7
No. 8	68.0	46.53	6.8	36.3	48.01	6.9	0.97	2.1
No. 9	89.1	69.40	8.3	62.8	88.23	9.4	0.79	3.6
No. 10	72.8	62.83	7.9	38.9	84.92	9.2	0.74	5.2
No. 11	97.2	68.13	8.3	66.5	85.39	9.2	0.80	1.4
No. 12	77.0	102.85	10.1	42.8	57.04	7.6	1.80[a]	9.8[b]
No. 13	77.6	66.28	8.1	32.4	83.23	9.1	0.80	12.2[b]
No. 14	83.2	60.69	7.8	36.2	72.05	8.5	0.84	4.5
Average	80.7		8.3[c]	45.8		8.0[c]		

* Variability of apparatus and technique, after elimination of variability caused by material and differences among arms.

[a] Highly significant, indicating lack of reproducbility of results due to apparatus or technique.

[b] Highly significant lack of consistency.

[c] $\bar{\sigma}$ = Square root of average of 14 individual σ^2,s.

by standard deviations. Although the precision of the average values from one or two laboratories may have differed significantly from the rest, none was significantly less precise for more than one material.

Since this experiment yielded sufficient data from the four materials for the individual arms, the analysis of variance technique can be used to eliminate the role played by the heterogeneity of arms and differences among materials and so obtain the intrinsic variability, σ^2, of the results from each laboratory. This intrinsic variability, listed by laboratories in Table VII, includes differences within the fabrics (known to be relatively minor) and the variability of the machines, exclusive of the effects of the arms. The intrinsic variability is shown to be the basic variability of the machines by the fact that approximately the same average value is obtained for all laboratories irrespective of abradant used. Therefore, it would be expected that within each laboratory, the ratio of the intrinsic variability obtained with emery abradant to that obtained with Aloxite abradant equals approximately unity. If this ratio is significantly greater than one for a laboratory, the reproducibility and consistency of its instrument would be seriously questioned. Consequently, the reproduci-

LABS	ABRADANT	HBT ARM				POPLIN ARM				SATEEN ARM				2/1 TWILL ARM				AVERAGE OF ALL FABRICS ARM				RANKING OF ARMS
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
1	E	97.3	93.0	89.7	91.7	99.6	97.0	89.9	97.6	74.4	67.7	62.3	63.1	70.6	63.3	58.9	65.4	85.5	80.2	75.2	79.5	3-42-1
	A	62.7	63.7	50.9	64.1	57.4	53.3	48.7	62.6	31.9	30.1	24.0	23.1	39.7	34.9	29.4	38.4	47.9	45.5	38.3	47.1	3-241
2	E	81.7	82.9	75.1	88.6	92.6	83.1	71.6	91.3	57.9	58.4	55.6	61.7	57.9	60.3	52.3	63.7	72.5	71.2	63.6	76.3	3-214
	A	41.4	53.3	38.6	53.4	21.7	29.9	32.4	43.7	13.0	18.9	16.1	19.7	20.0	24.4	15.7	28.1	24.0	31.6	25.7	36.3	13-24
3	E	92.4	92.0	99.1	92.9	96.3	106.0	105.7	99.6	63.1	67.9	65.1	64.0	72.7	69.7	71.9	74.3	81.1	83.9	85.5	82.7	1423
	A	75.4	83.3	81.6	77.0	60.9	59.0	59.1	58.0	37.3	40.1	33.9	38.7	40.3	44.7	47.0	38.4	53.5	56.8	55.4	53.0	4132
4	E	98.4	97.6	95.3	95.7	107.9	113.0	106.0	100.0	72.1	81.0	74.7	72.6	73.6	68.4	67.9	69.4	88.0	90.0	86.0	86.4	341-2
	A	74.1	74.7	59.4	77.7	44.9	61.3	36.9	53.4	46.9	47.0	31.9	42.0	36.3	34.0	32.6	38.0	50.5	54.2	40.2	52.8	3-142
5	E	96.3	89.1	94.6	91.0	83.4	79.4	90.1	87.4	53.4	60.0	58.3	59.4	63.9	64.9	72.4	73.6	74.2	73.4	78.9	77.9	214-3
	A	83.3	82.1	85.3	86.7	36.0	37.3	46.0	51.3	25.1	24.9	33.6	30.7	43.7	43.0	53.3	45.4	47.0	46.8	54.5	53.5	214-3
6	E	104.9	96.6	99.1	95.3	98.6	92.4	87.4	79.0	69.7	59.3	70.3	57.1	78.0	73.3	65.9	59.4	87.8	80.4	80.7	72.7	4-23-1
	A	78.4	72.0	67.7	54.3	60.6	59.6	45.9	36.0	43.7	37.1	30.3	19.0	55.3	46.3	38.7	39.3	59.5	53.7	45.6	37.1	4-32-1
7	E	91.9	92.0	96.4	97.4	108.3	107.0	101.9	101.1	79.7	71.7	76.4	69.3	81.0	68.9	68.9	75.3	90.2	84.9	85.9	85.8	243-1
	A	71.1	58.4	60.1	66.4	41.0	43.0	43.0	59.6	42.0	30.9	33.4	42.0	42.9	42.9	38.6	52.1	49.2	43.8	43.8	55.0	231-4
8	E	85.1	80.9	84.0	81.3	72.3	77.7	97.7	75.0	39.9	40.9	50.1	41.1	67.7	69.0	66.1	59.7	66.2	67.1	74.5	64.3	412-3
	A	51.7	47.4	51.6	41.7	35.4	36.3	31.6	30.6	28.6	23.1	32.3	26.9	35.7	36.0	35.9	32.3	37.9	35.7	38.8	32.9	4-213
9	E	95.3	100.1	100.7	99.6	102.7	104.7	106.0	89.7	76.4	87.6	84.6	80.7	71.4	74.6	72.4	78.7	86.5	91.7	90.9	87.2	14-32
	A	83.4	86.6	84.3	88.1	44.9	62.3	72.0	61.9	43.6	67.0	61.1	55.9	50.6	50.4	47.1	45.4	55.6	66.6	66.1	62.8	1-432
10	E	80.4	92.7	87.3	87.1	74.9	92.9	85.4	82.7	56.9	68.4	56.3	53.7	56.9	66.1	62.1	60.3	67.2	80.0	72.8	71.0	1-43-2
	A	45.6	79.7	58.7	54.0	28.0	53.4	28.7	35.7	20.1	29.9	17.3	19.4	28.7	43.4	45.9	33.1	30.6	51.6	37.6	35.6	1-43-2
11	E	104.6	104.3	104.7	103.9	112.3	116.6	116.1	109.9	84.6	81.0	95.1	86.6	82.3	83.7	89.6	80.4	95.9	96.4	101.4	95.2	412-3
	A	83.6	85.4	84.1	75.3	71.7	77.7	74.9	63.3	58.7	54.7	59.4	62.6	55.9	60.3	47.9	48.7	67.5	69.5	66.6	62.5	4132
12	E	96.9	88.4	98.1	93.1	84.7	84.0	86.9	91.7	61.9	58.4	67.1	61.4	65.7	57.4	68.6	67.7	77.3	72.1	80.2	78.5	2-143
	A	75.4	67.3	80.0	65.6	30.7	28.1	33.7	33.9	33.4	23.3	25.3	31.7	36.6	35.4	43.4	40.9	44.0	38.5	45.6	43.0	2-413
13*	E	84.1	90.1	94.7	----	95.1	80.4	95.9	----	58.0	64.4	64.6	----	67.7	67.4	69.1	----	76.2	75.6	81.1	----	21-3
	A	44.1	49.4	60.4	----	6.7	12.7	41.3	----	14.9	21.7	28.3	----	32.1	26.6	51.0	----	24.5	27.6	45.2	----	12-3
14	E	94.3	95.4	98.4	98.7	91.6	85.0	91.6	104.4	69.6	65.3	74.6	75.9	70.1	73.9	67.4	74.4	81.4	79.9	83.0	88.4	321-4
	A	42.3	45.6	64.6	61.7	26.3	21.3	30.3	37.7	30.4	22.1	30.7	38.6	30.0	23.3	35.1	39.1	32.2	28.1	40.2	44.3	213-4

*THREE-ARM MODEL

bility of the results from laboratories Nos. 5 and 12 would be doubtful, their values for the ratio being 2.19 and 1.80, respectively, instead of being approximately 1.0.

The internal consistency can be checked by using the chi-square technique, which evaluates the discrepancy between the values theoretically obtained on the basis of the assumption and the actual values. In this case, the chi-square analysis was used to ascertain significance of the difference between the actual and the theoretical ratios of the average residual breaking strengths of the four fabrics using each abrasive. The theoretical ratios were computed on the assumption that the residual breaking strength of each of the materials abraded in a laboratory should form a constant ratio regardless of the abradant in order that the results of a laboratory be considered consistent.

The lack of reproducibility of laboratories 5 and 12 conclusion is substantiated by their lack of consistency, for their values of χ^2 are 7.8 and 9.8, respectively. The high value of χ^2 for laboratory No. 13 is a result of a sharp reversal of the data when emery and Aloxite were used.

Contributory Causes of Variability:

Hitherto the discussion of results has not considered possible causes of the heterogeneity of the arms, but a study of the Wyzenbeek tester would not be complete without an analysis of this factor. The data of Table VIII, which are the average breaking strengths of the specimens inserted into each arm of each instrument, show the arms which yield results significantly different from their mates. As the rubber pads used in the Wyzenbeek apparatus may differ considerably in physical characteristics, and thus in their abrading efficiency, employment of homogeneous pads would result in greater reliability. Further, by bringing the differing arm into line with the others, much closer control limits would be obtained. In a separate experiment, interchanging the pads among the arms of a single instrument resulted in a reranking of the arms. Thus, differences in the rubber abrading pads are an important factor contributing to the differences among instruments, but it is not the only machine factor.

This study indicates that the use of No. 0 emery abradant yields results having 50 per cent less variability than does the use of No. 320 Aloxite abrasive. As previously mentioned, an excellent consistency exists in the individual evaluation of all the fabrics tested by each laboratory when emery is employed. The consistency is much less apparent when Aloxite is used.
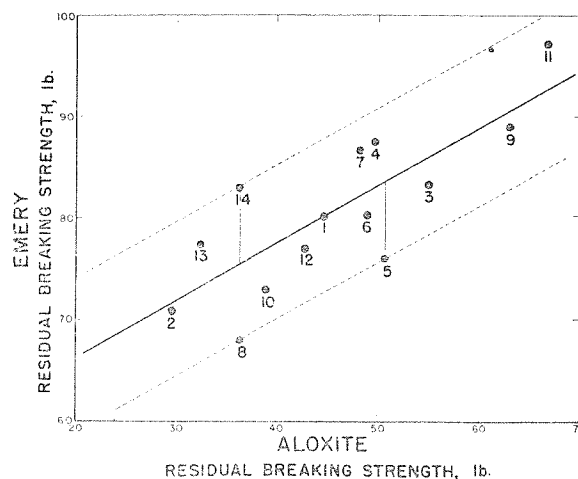

Fig. 6.—Consistency of Individual Wyzenbeek Machines.

A comparison of the two types of end points is made possible by the two inter-laboratory tests since herringbone twill fabric was used in each. In the first test a subjective end point was studied, namely, the number of cycles of abrasion required to produce a described change in appearance. In the second test the

2. It cannot be employed in establishing a general standard.
3. Increase in precision may be achieved by
   (a) using an objective end point whenever feasible;
   (b) employing a mild uniform abradant;

TABLE IX.—VARIABILITIES OF THE TWO TYPES OF END POINTS USING EMERY ABRADANT AND HERRINGBONE TWILL FABRIC.

| | Objective End Point, Loss in Breaking Strength, per cent | Subjective End Point | | | |
| | | 1st Rupture | | Threadbare | |
		W	F	W	F
Per cent Deviation from Mean:					
Average	21.7	68	64	56	59
Range	50.6	261	295	175	210
Coefficient of Variation, V	30.2	104	109	78	87
Ratio of V_{sub}/V_{obj}	....	3.5	3.6	2.6	2.9

end point was objective, for the loss in breaking strength after an arbitrary number of cycles of abrasion was noted. Comparative values of the coefficients of variation among laboratories for the two end points are shown in Table IX.

From this table, it will be seen that the coefficients of the subjective end points are approximately thrice that of the objective end point.

CONCLUSIONS

On the basis of the results reported in this paper, the following conclusions may be stated:

1. In its present state, the Wyzenbeek Precision Wear Test Meter can be used:
   (a) In evaluating differences among materials by a given laboratory;
   (b) For interlaboratory checks by cooperating laboratories if their instruments are predetermined to be sufficiently similar in abrasive action and reproducibility.

   (c) utilizing control chart techniques to ensure consistency among arms and tests.

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